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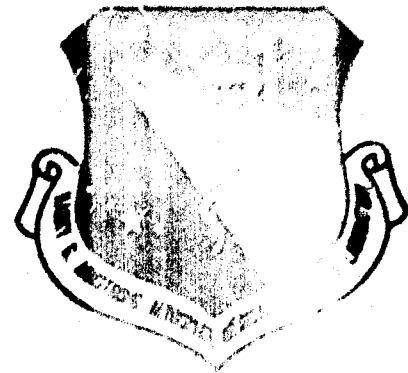
FURTHER INVESTIGATION OF CONTRAST SENSITIVITY AND VISUAL ACUITY IN PILOT DETECTION OF AIRCRAFT(U)

AD-A198 434

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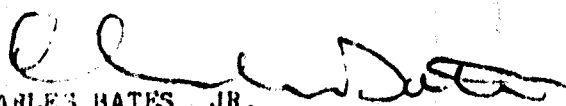
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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Director, Human Engineering Division
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The relationship between visual function and aircraft detection was investigated using 67 USAF pilots. Contrast sensitivity was measured using the 2-AFC technique on the Optronix and with the Vistech chart. Visual acuity was assessed at three (3%, 6%, and 85%) chart contrasts. Pilots detected an approaching T-38 jet during 8 landings in 8 separate groups. Mean detection distance ranged from 4.77 to 6.73 miles for each group. For these partly-cloudy to cloudy test conditions, neither contrast sensitivity nor visual acuity correlated well with detection distance. There was a lack of consistency for the contrast sensitivity at any particular spatial frequency to correlate with detection. The best indicator of subjects with worse detection distances was performance on the visual acuity charts, but lower contrast sensitivity rarely identified the subjects with shorter detection distances. Neither contrast sensitivity nor visual acuity was able to identify the pilots with the best detection distances. Keywords: Flight Crews, Vision, Visual perception, (SD)

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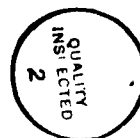**DD Form 1473, JUN 86**   Previous editions are obsolete.   SECURITY CLASSIFICATION OF THIS PAGE

SUMMARY

Contrast sensitivity (CS) has been reported (Ginsburg et al., Human Factors Society meeting, 1983) to be strongly related to pilots' aircraft detection performance, suggesting that CS should be assessed in pilots. However, examination of their results shows a lack of consistency for the CS at any particular spatial frequency to correlate with detection, even for days with similar visibility conditions. To further investigate this relationship, sixty-seven (67) U.S. Air Force pilots were divided among 8 groups, positioned near a runway on separate days, and detected an approaching white T-38 jet aircraft during 8 landings. Weather varied between test days from partly-cloudy to cloudy, with visibility conditions ranging from 7-10 miles and 2,000-5,000 foot cloud ceilings. Using other test personnel, CS was measured using the criterion-free two-alternative, temporal forced-choice (2-AFC) technique on the Optronix and with the Vistech VCTS 6500 chart. Visual acuity was assessed at three contrast levels using 3%, 6%, and 85% measured contrast Regan charts. The mean detection distance of each group ranged from 4.77 to 6.73 miles, and intersubject difference within any group was 0.64 to 1.76 miles. Neither contrast sensitivity nor visual acuity correlated well with pilot detection of actual aircraft. Overall, correlations were significant in only 3 of 40 (7.5%) and 7 of 48 (14.6%) spatial frequency CS vs detection distance comparisons for the Vistech VCTS and Optronix CS, respectively. For visual acuity the percentage was slightly better, with correlations significant in 7 of 24 (29.2%) acuity vs detection distance comparisons. There was a lack of consistency under these similar visibility conditions for the CS at any particular spatial frequency to correlate with detection distance. A significant ($p < 0.05$) positive correlation was found for only one field trial group at any one spatial frequency for either CS test. The highest percentage of field trials, 50% (4 of 8 trials), showed a significant correlation for 6% contrast acuity vs detection distance. The best indicator of subjects with worse detection distances was performance on the visual acuity charts; but lower contrast sensitivity rarely identified the subjects with shorter detection distances. Neither visual acuity nor contrast sensitivity was able to identify the pilots with the best detection distances.

PREFACE

TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Contrast sensitivity testing has been reported to be useful in the detection and monitoring of a number of ocular conditions.[1-3] In addition, contrast sensitivity has also been purported to differentiate among USAF pilots with normal visual acuity. In a simulator based study under low visibility conditions, Ginsburg et al.[4] reported that pilots' scotopic contrast sensitivity correlated with detection of an aircraft on a runway. Ginsburg et al.[5] further stated that contrast sensitivity, and not visual acuity, was strongly related to pilots' aircraft detection performance in a field study; suggesting that contrast sensitivity should be assessed in pilots and used in initial pilot selection. In a technical report, Stager and Hameluck[6] reported that photographic crash site detection by Canadian Search and Rescue personnel was related to their contrast sensitivity at 12 to 18 cpd, but visual acuity frequently showed a reverse relationship.

However, Kruk et al.[7,8] found in two studies that contrast sensitivity did not correlate, nor did visual acuity, with pilot flying performance in a simulator. Further, Kruk and Regan[9] reported that during actual in-flight, air-to-air maneuvers neither contrast sensitivity nor visual acuity correlated with pilot detection of an "enemy" fighter aircraft. In addition, in a large scale study involving 91 U.S. Navy pilots flying 600 air-to-air combat missions, Monaco and Hamilton[10] found that the pilots' visual acuity on both high and low contrast charts related better with their air-to-air aircraft detection than did their contrast sensitivity at either of six spatial frequencies; although neither visual performance measurement correlated highly.

These studies do not, however, appear to be unequivocal. For instance, in the simulator study by Ginsburg et al.[4] three visibility conditions (daytime, nighttime, and fog) were flown, but the only correlation reported was between the peak of the scotopic contrast sensitivity and detection of a Mig at the end of a runway under low visibility, presumably fog. Since the other

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Contrast sensitivity is the reciprocal of the contrast threshold at which a sine-wave grating pattern is just detected. A sine-wave grating is a repetitive sequence of light and dark bars whose luminance varies sinusoidally with distance, giving the appearance of "fuzzy-edged" bars. The number of light/dark bar cycles per degree visual angle (cpd) is the spatial frequency of the grating pattern. The threshold to contrast varies for gratings of different spatial frequency.

possible correlations were not reported, it is unknown if any significant correlation occurred between the normal photopic measured contrast sensitivity at any spatial frequency and target detection under either of the visibility conditions. Examination of the results in the field study by Ginsburg et al.[5] (see Appendix A) shows that over their 10 test sessions there was a lack of consistency in the correlation for any particular spatial frequency, even between days with similar visibility conditions. Few correlations were significant for any spatial frequency and many were either low or negative.

In addition, both of these studies measured contrast sensitivity using the method of increasing contrast on the Optronix. It is known the contrast threshold found using this presentation method is influenced by the threshold criterion of the subject.[11] It is possible that a pilot used similar criterion (e.g. conservative) for both the method of increasing contrast test and during aircraft detection that could lead to criterion-influenced correlations. Indeed, it was reported in the simulator study that some subjects "detected" the Mig when it was just a circular blob, other subjects when it was an elliptical blob, and still others as a distinct, L-shaped profile with a discernible vertical stabilizer. Clearly, subjects were using a variety of aircraft detection criteria ranging from unconservative to very conservative that may also have been used by the same subject during contrast sensitivity measurement.

In the study of Stager and Hameluck,[6] visual acuity was scored on three acuity sizes (20/20, 20/15, and 20/10), and each score was then used separately in the subsequent correlations. This lack of independence between the acuity scores (eg. all 20/10 subjects would have read correctly all letters on the other two lines, and vice versa) would clearly affect any correlation of acuity with detection. A single acuity score for each subject would have eliminated this effect and given a truer indication of the relationship between acuity and detection. In addition, they used a step-wise multiple regression analysis, which selects the highest correlating variable and then chooses the next variable that increases the predictive ability of the resulting equation. This can lead to the next highest correlating variable being ignored completely, and allow other less contributing variables to appear in the predictive equation. Additional analysis, a Spearman correlation matrix supplied by the authors (private communication), showed significant ($p <$ 0.05) correlations in only 4 of 19 and 3 of 19 test photograph conditions for the contrast sensitivity at 12 and 18 cpd, respectively. Overall, for the complex terrain scenes used in this study, a higher percentage of negative correlations were actually found for contrast sensitivity (36.7%) than for visual acuity (27.8%).

The three Kruk et al.[7-9] studies evaluated the correlation between flying performance and aircraft detection range at only one, 5 cpd, spatial frequency. A wider range of spatial frequencies would have more completely determined the relationship between contrast sensitivity and these tasks. Clearly, additional research is needed on the relationship between contrast sensitivity and actual performance in normals before contrast sensitivity testing of pilots can be considered.

In this study, to control patient criterion and obtain a better threshold measurement,[11,12] contrast sensitivity was measured using the criterion-free two-alternative, temporal forced-choice (2-AFC) method of presentation. The Vistech VCTS 6500 contrast sensitivity chart was also used in order to assess its usefulness in screening pilots with normal vision. To more completely assess visual acuity, three different chart contrasts were used and acuity on each chart was quantified in logMAR (logarithm of the minimum angle of resolution), which gives a more exact quantification of visual acuity than is typically determined. The T-38 jet was used for target detection for its similarity to fighter-type aircraft. In addition to determining the correlation of visual performance with aircraft detection distance, the vision tests were also evaluated for their ability to identify those pilots with the shortest detection distances.

METHODS

Subjects:

Sixty-seven (67) USAF pilots (mean age: 27.5 years, 22 – 40 years) attending pilot instructor school at Randolph AFB, Texas participated in both the indoor and outdoor portions of the study (111 completed the indoor portion), conducted simultaneously during the period 8 – 19 September 1986. The pilots were volunteers and informed consent was obtained from each subject. Pilot confidentiality was maintained by identifying each pilot by number only. Spectacle corrections for distance vision were worn during all testing. Due to pilot flight commitments, the order of participation in the indoor and outdoor tests was mixed, only one indoor vision measurement session was allowed, and a variable number of pilots were available for each outdoor field trial.

Visual Acuity:

Visual acuity at three contrasts was assessed using Regan charts having measured modulation contrasts of 3%, 6%, and 85%. The charts were individually presented from low to high contrast at a mean white matte luminance of 150 cd/m^2. Charts were presented at 20 feet, twice the chart design distance, to eliminate truncation of the smallest letter size available. To measure visual acuity better than is typically determined using standard Snellen charts, acuity was quantified in logMAR (logarithm of the minimum angle of resolution) using charts having an equal 0.10 log unit letter size progression between rows, that contain an equal number of letters on each row, and in which contour interaction between letters is the same by maintaining a separation of one letter width between the letters on each row, giving the chart a V appearance.[13] Each of the 8 letters per row was given a log value of 0.0125, and the acuity score was the logMAR for the number of letters read correctly on the lowest line that a mistake occurred.

2-AFC Optronix Contrast Sensitivity:

Binocular spatial contrast sensitivity was measured using a computer program adapted Nicolet Optronix CS 2000 Contrast Sensitivity Testing System. Vertical sine wave gratings were presented on a video monitor with mean luminance of 60 cd/m^2 and backed by an off-white wall. Subjects were seated 8.7 feet (265 cm) from the monitor, at which the gratings subtended a visual angle of about 4° by 5°. Contrast thresholds were measured for six stationary spatial frequency gratings of 1.5, 3, 6, 12, 18, and 24 cycles/degree (cpd). Contrast, as defined by Michelson, was: $C = (L_{max} - L_{min}) / (L_{max} + L_{min})$, where L_{max} and L_{min} are the maximum and minimum luminances of the grating bars. The grating size, contrast, and luminance were calibrated daily.

The importance of controlling individual threshold criterion in the measurement of contrast sensitivity has been reported.[11,12] Thus, the method of presentation was the criterion-free two-alternative, temporal forced-choice (2-AFC) procedure using a computer program developed by Mark Cannon, Ph.D. of AAMRL (available on request). The subject indicated in which of two 500 millisecond time intervals the grating appeared. Each interval was preceded by a single auditory tone and the subject was signaled to respond by a double auditory tone. Subjects indicated their response using a toggle switch, after which the next presentation sequence began 500 milliseconds later. Subjects could rest by delaying their response and between each spatial frequency. Contrast decreased after 4 successive correct responses and increased after 1 incorrect response. Contrast threshold was the geometric mean (mean of log contrast) for 6 reversals, 3 upper and 3 lower. Although a larger number of reversals would have been desirable, pilot availability for a longer indoor test session was restricted. The group mean and upper and lower standard deviation limits were calculated from the individual log contrast values.

Vistech VCTS 6500 Contrast Sensitivity Chart:

The Vistech chart is a large 27 x 37 inch wall-mounted white matte panel containing five rows of nine circular patches. The chart was illuminated by a specially constructed holder containing long fluorescent lamps both above and below the chart, giving fairly even white matte luminance of 150 cd/m^2. Each patch is 3 inches in diameter and subtends 1.4° at the 10 foot test distance. The patches contain sine wave gratings oriented either vertically or tilted 15° from vertical towards the right or left. Each row has patches with a single spatial frequency of 1.5, 3, 6, 12, or 18 cpd. The first patch in each row is a high contrast example of the spatial frequency and the last patch has no grating pattern, leaving seven patches having successively lower contrast for testing. To reduce individual criterion effects, the chart was presented as a three-alternative forced choice for each patch. Since a response on each patch was mandatory and a response of blank was not allowed, scoring was the last correct response just prior to the first error in each row.

Field Trials:

Pilots appeared for outdoor testing based upon their individual flight schedules. Only one group of pilots was tested on each of the eight field test days. Each group was in a bus positioned near the beginning of the runway, and subjects were individually isolated using opaque cloth partitions and earplugs. Field trials were conducted between 2-4:00 pm, the sun was behind the subjects, and bus windows were open. The weather varied between days from partly-cloudy to cloudy, with visibility conditions ranging from 7-10 miles and 2,000-5,000 foot cloud ceilings. Subjects pressed a button connected to an automated timer device upon detecting an approaching white T-38 jet aircraft straight ahead at 1,000 feet altitude and 175 knots (200 mph) airspeed during about 8 landings. All sightings were greater than the 2.5 mile distance at which aircraft are required to turn on landing lights.

Individual subject data is given for each group in Appendixes C - J.

RESULTS

Visual Performance Results

Visual Acuity:

The mean visual acuity values and acuity ranges for the 67 pilots at each of the three chart contrasts are given in Table 1. Visual acuity varied over a wide range for each chart contrast. For these pilots, the mean visual acuity on the normal high contrast chart was much better than the usual standard of 20/20, and was closer, though better, to the 20/15 acuity frequently found during eye examinations. Acuity on the 6% contrast chart still remained relatively well, with the mean at about 20/18 and the best acuity at 20/13. For comparison with the typical plot of the contrast sensitivity function, Figure 1 shows the mean, 1 SD, and range of acuities in minimum angle of resolution (minutes of arc), as derived from the logMAR values, and gives the corresponding Snellen acuity and representative calculated spatial frequencies. The visual acuity data, as calculated in spatial frequency, appear to continue the contrast threshold curve to a mean limit of about 55 cpd (see triangles on Figure 2).

TABLE 1. VISUAL ACUITY

	CHART CONTRAST		
	3%	6%	85%
MEAN LOGMAR	0.137 ±0.09	− 0.035 ±0.07	− 0.264 ±0.06
MEAN MAR	1.37	0.92	0.54
MEAN SNELLEN	20/27.4	20/18.4	20/10.9
LOGMAR RANGE	0.413 to − 0.050	0.150 to − 0.175	− 0.100 to − 0.363
SNELLEN RANGE	20/51.8 to 20/17.8	20/28.3 to 20/13.4	20/15.9 to 20/8.7

LOGMAR: LOGARITHM OF MINIMUM ANGLE OF RESOLUTION

MAR: MINIMUM ANGLE OF RESOLUTION (MINUTES OF ARC)

VISUAL ACUITY
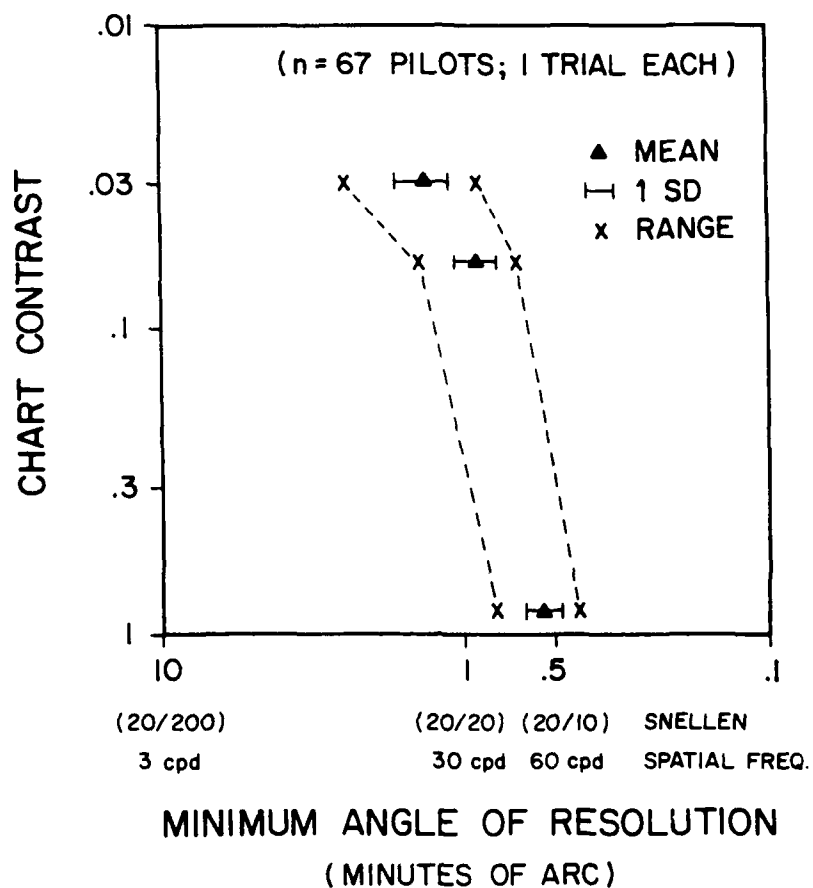
Figure 1. Visual acuity (minimum angle of resolution) on Regan charts having 3%, 6%, and 85% measured contrasts for 67 USAF pilots (mean age: 27.5 years, 22-40 years), one trial each. The corresponding Snellen acuity and representative calculated spatial frequencies are also shown.

2-AFC Optronix Contrast Sensitivity:

The mean, one standard deviation limits, and range of contrast sensitivity values for the 67 pilots at each of the six spatial frequencies tested using 2-AFC on the Optronix are given in Table 2, and the usual graphical display is shown in Figure 2. Contrast sensitivity varied over a wide range at each spatial frequency, with a 5 – 7 times difference between the lowest and highest sensitivity for most spatial frequencies. The contrast sensitivity curve follows the typical relationship between sensitivity and spatial frequency; with the peak sensitivity at 3 cpd being slightly higher than that at either 1.5 or 6 cpd, and a decrease in sensitivity at higher frequencies. These data agree reasonably well with those of other reports using the Optronix.[14,15] For relative comparison, the mean acuity values, as calculated in corresponding spatial frequency, for the three chart contrasts are also shown in Figure 2; and appear to continue the CSF to a mean limit of about 55 cpd.

TABLE 2.　2-AFC OPTRONIX CONTRAST SENSITIVITY

| SPATIAL | CONTRAST SENSITIVITY: | | |
FREQ (C/D)	MEAN	1 SD LIMITS	RANGE
1.5	256	176-373	(95-520)
3	314	227-434	(135-540)
6	277	196-391	(125-620)
12	109	71-167	(35-265)
18	45	29-68	(15-95)
24	19	14-26	(9-35)
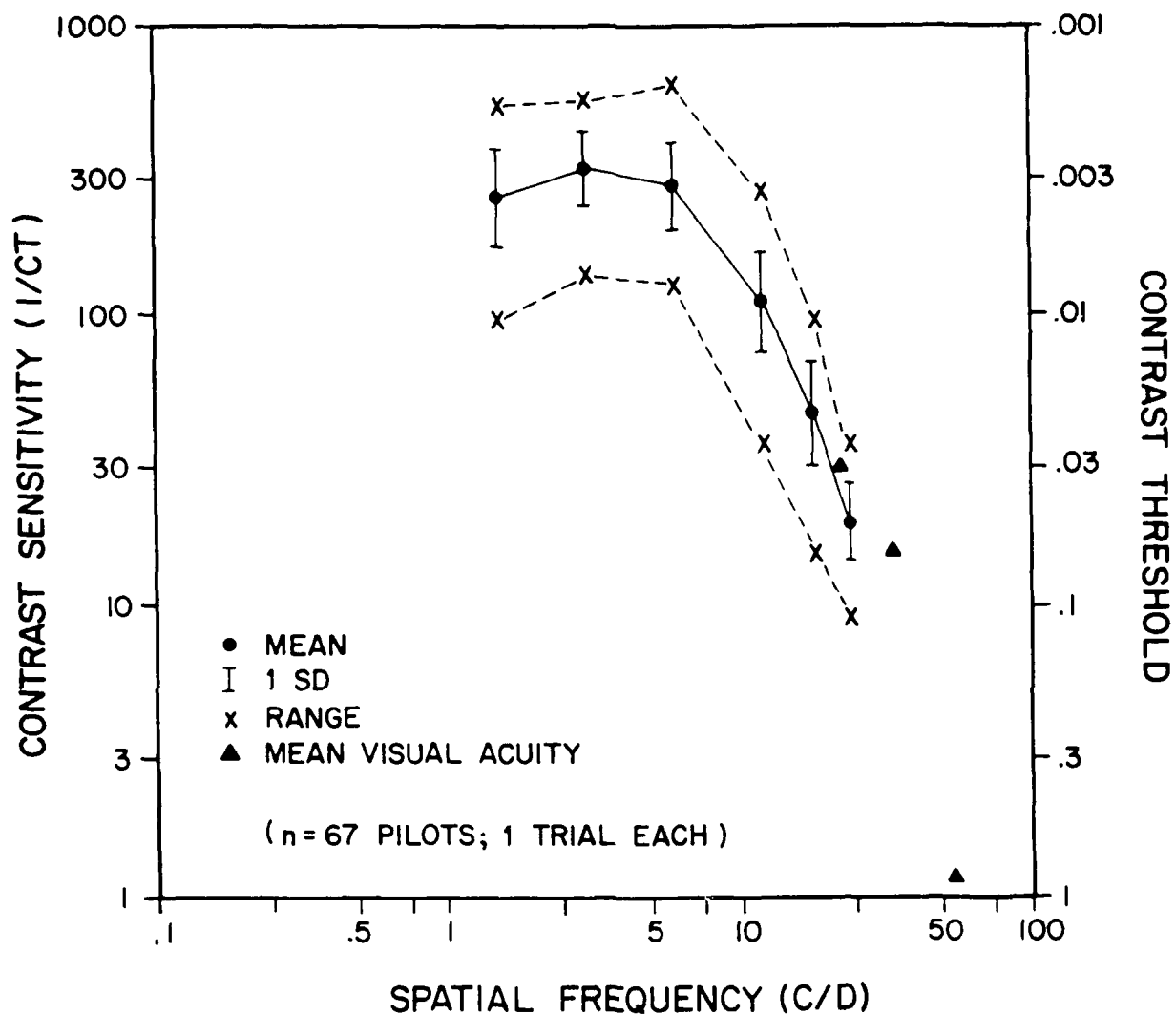
Figure 2. Contrast threshold and contrast sensitivity using two-alternative forced choice (2-AFC) on the Optronix for for 67 USAF pilots (mean age: 27.5 years, 22-40 years), one trial each. Visual acuity results (triangles) are shown for comparison.

14

Vistech Chart:

Mean patch number scores for the 67 pilots at each spatial frequency on the Vistech chart are given in Table 3. The chart test patches are numbered between 1 (highest contrast) and 8 (lowest contrast). These mean values are close to the maximum (8) for the chart and are much higher at all spatial frequencies than the means supplied with the chart (5, 6, 6, 5, and 4 for 1.5, 3, 6, 12, and 18 cpd, respectively) for a general population; but only slightly higher than those reported for another well corrected, young population.[15] The range of scores was narrow for each spatial frequency, limiting the ability of this chart to differentiate among normals, and the lowest score was well within normal. (Although contrast sensitivity values for each patch were supplied with the chart, these values were not used since they were recently changed in a letter issued by Vistech and need further validation prior to their use.)

TABLE 3. VISTECH VCTS 6500 CHART SCORE

SPATIAL FREQ (C/D)	MEAN		SCORE: SD	RANGE
1.5	7.22	±	0.69	(6-8)
3	7.60	±	0.58	(6-8)
6	7.67	±	0.56	(6-8)
12	7.39	±	0.78	(5-8)
18	7.00	±	0.94	(5-8)

Aircraft Detection Results

Correlation of visual performance with detection distance:

A summary of the visibility conditions, T-38 jet aircraft detection distances, and the correlation matrix of visual performance with detection distance for each field trial group are shown in Figure 3. Weather varied between test days from partly-cloudy to cloudy, with visibility conditions ranging from 7 – 10 miles, and 2,000 to 5,000 foot cloud ceilings. The mean detection distance of each group ranged from 4.77 to 6.73 miles, and intersubject difference within any group was 0.64 to 1.76 miles. The variability in meteorological conditions between test days precludes combining the data, and correlations were determined for each field group separately. Nonparametric correlation analysis was generally higher than parametric correlations, and is reported here.

In general, there were few significant correlations with aircraft detection distances for either contrast sensitivity or visual acuity; although the overall percentage was higher for visual acuity. Correlations were significant in only 3 of 40 (7.5%) and 7 of 48 (14.6%) spatial frequency contrast sensitivity vs detection distance comparisons for the Vistech VCTS and Optronix contrast sensitivity, respectively, and 7 of 24 (29.2%) of the visual acuity vs detection distance comparisons. More importantly, there was a lack of consistency under these similar visibility conditions for the contrast sensitivity at any particular spatial frequency to correlate with detection distance. A significant positive correlation was found for only one field trial group at any one spatial frequency for either contrast sensitivity test. This lack of significant correlations was also found for the 3% and 85% contrast charts. The highest percentage of field trials, 50% (4 of 8 trials), showed a significant correlation for 6% contrast acuity vs detection distance.

16

CORRELATION (r) OF CONTRAST SENSITIVITY AND VISUAL ACUITY WITH AIRCRAFT DETECTION DISTANCE

FIELD TRIAL	AIRCRAFT DETECTION DISTANCE (MILES)+				NONPARAMETRIC CORRELATION (r) WITH DETECTION DISTANCE											VISUAL ACUITY		
					VISTECH CHART					2-AFC OPTRONIX								
DATE (n) WEATHER*	MEAN	LONG -est	SHORT -est	Dif.	(c/d)					(c/d)						CHART CONTRAST		
					1.5	3	6	12	18	1.5	3	6	12	18	24	3%	6%	85%
9/8 (n=10) CLOUDY	5.06	5.32	4.59	0.73	S .20	.25	-.25	-.29	-.50	S -.01	S 17	S .21	S .02	-.24	S .07	-.03	.22	-.41
9/9 (n=9) PRT-CLOUDY	5.85	6.35	5.35	1.00	-04	.58	.28	.63	.35	.02	-.27	.19	L .25	L .17	L -.04	S .72	S .82	.19
9/11 (n=6) PRT-CLDY	6.35	7 26	5.50	1 76	88	.21	-.83	-.29	.21	S .77	.12	-.23	.50	S .31	.43	S -.03	LS .83	S .26
9/12 (n=8) OVERCAST	4.77	5 73	3.99	1 74	.11	.00	S .30	-.11	-.29	S .20	S .35	S .46	S .33	S .25	.49	S .19	S .04	S .54
9/15 (n=8) CLOUDY	6.33	6.87	5.42	1.45	S -.17	.24	-.08	-.03	.10	-.14	-.28	-.17	-.36	L .21	L .64	.18	S .69	19
9/16 (n=8) PRT-CLDY	5.34	5.98	4.48	1.50	-.19	.25	-.38	.26	S .05	-.77	.66	.50	.28	-.03	-.01	S .08	- 17	S .04
9/17 (n=9) OVERCAST	5.21	5.64	4 83	0.81	S .38	-.10	S .55	.11	.17	.07	-.14	L .68	67	LS .61	-.01	S .72	LS .90	L .79
9/19 (n=9) CLOUDY	6.73	7.07	6.43	0.64	-.30	-.47	.32	.04	-.01	-.36	-.49	.11	.18	- 14	- 16	.26	.00	42

* VISIBILITY 7-10 MILES ON ALL DAYS, CEILING 2,000 TO 5,000 FEET

\+ AIRCRAFT SPEED 175 KNOTS (200 MPH), 18 SECONDS/MILE

▼ CORRELATION SIGNIFICANT TO 0.05 LEVEL OR BETTER

L LONGEST DETECTION DISTANCE CORRESPONDED TO HIGHEST CONTRAST SENSITIVITY OR BEST VISUAL ACUITY

S SHORTEST DETECTION DISTANCE CORRESPONDED TO LOWEST CONTRAST SENSITIVITY OR WORST VISUAL ACUITY

Figure 3. Summary of visibility conditions, T-38 jet aircraft detection distances, and correlation of contrast sensitivity and visual acuity with detection distance for 67 USAF pilots divided among 8 field trial test days. Neither contrast sensitivity nor visual acuity correlated well with aircraft detection distance.

Comparison of detection distance correlation coefficients:

Statistical comparisons (Wilcoxon rank sum) between the detection distance correlation coefficients for visual acuity at each chart contrast versus those for contrast sensitivity at each spatial frequency on the Optronix are given in Table 4. In all but one comparison, visual acuity correlated better with detection distance than did contrast sensitivity. However, only two comparisons were significant, and overall there was no difference in the predictive ability of aircraft detection performance (i.e. detection distance correlation coefficients) between contrast sensitivity and visual acuity. Comparisons between the detection distance correlation coefficients for visual acuity and the Vistech chart were also not significant, and were similar to those shown.

TABLE 4. STATISTICAL COMPARISON BETWEEN CORRELATION COEFFICIENTS

(WILCOXON RANK SUM)

PROBABILITY LEVEL:

CHART CONTRAST	2-AFC OPTRONIX (C/D)					
	1.5	3	6	12	18	24
3%	0.09	0.08	0.44	0.40 +	0.26	0.20
6%	0.04*	0.04*	0.14	0.23	0.10	0.09
85%	0.06	0.09	0.42	0.46	0.23	0.23

* SIGNIFICANT DIFFERENCE

+ CONTRAST SENSITIVITY SUM > VISUAL ACUITY SUM IN ONE CASE

VISUAL ACUITY SUM > CONTRAST SENSITIVITY SUM IN ALL OTHER CASES

- OVERALL, NO DIFFERENCE BETWEEN VISUAL ACUITY AND CONTRAST SENSITIVITY CORRELATION COEFFICIENTS WITH DETECTION DISTANCE.

Ability of vision test to identify worse detection pilots:

Although a group of individuals with excellent vision may not reveal an overall correlation with a specific task performance, a particular vision test may still be useful if it can identify individuals with worse task performance. To determine this ability, the relationship between lower performance on each of the vision tests and target detection distance was also evaluated. Of those pilots scoring in the lower 10% of visual performance (i.e. 1.3 standard deviation below the mean) on the visual acuity and Optronix contrast sensitivity tests, the number of pilots that also had the shortest or next shortest detection distance in their group are given in Table 5.

TABLE 5. ABILITY OF VISION TEST TO IDENTIFY WORSE DETECTION PILOTS

(PILOTS WITH SHORTEST OR NEXT SHORTEST DETECTION DISTANCE OF THOSE IN LOWER 10% OF VISUAL PERFORMANCE, 1.3 SD BELOW MEAN.)

	SHORTEST	SHORTEST + NEXT SHORTEST
VISUAL ACUITY		
3%	3 OF 5	3 OF 5
6%	4 OF 5	5 OF 5
85%	4 OF 8	6 OF 8
OPTRONIX		
1.5	2 OF 6	2 OF 6
3	2 OF 7	2 OF 7
6	1 OF 6	1 OF 6
12	1 OF 6	1 OF 6
18	1 OF 6	2 OF 6
24	1 OF 4	2 OF 4

Pilots with visual acuity in the lower 10% were frequently also the pilots with the shortest or next shortest detection distance in their group. However, it should be noted these pilots still had excellent normal high contrast chart acuity, with worst acuity still at 20/15. Performance on the 6% contrast acuity chart was the best identifier of pilots with shorter detection distances. Of the 5 pilots with visual acuity of less than 20/20 on the 6% contrast chart, all 5 were also worse detection pilots in their group. Contrast sensitivity showed little ability to identify the worse detection pilots, since those pilots with contrast sensitivity in the lower 10% were rarely those with shorter detection distances in their group. The Vistech chart was unable to identify the worse detection pilots since a number of subjects usually had the same lower score at each spatial frequency.

Ability of vision test to identify best detection pilots:

Pilots with visual acuity or contrast sensitivity in the upper 10% (i.e. 1.3 standard deviation above the mean) were rarely also the pilots with the longest or next longest detection distance in their group. Neither visual acuity nor contrast sensitivity was able to identify the best detection pilots.

DISCUSSION

Neither the contrast sensitivity nor visual acuity of pilots correlated well with their field performance in aircraft detection under the visibility conditions of this study. For these partly-cloudy, cloudy, and overcast visibilities, there was no repeatability (only 1 of 8 groups) for the contrast sensitivity at any spatial frequency to correlate significantly with aircraft detection. Normal high contrast chart visual acuity also did not correlate well with aircraft detection distance; however, this may be expected since the worst acuity was still about 20/15. Only 17 of the 112 comparisons were significant; and this degree of correlation is tempered by the expectation that, at the 0.05 level, 5.6 of the comparisons would be significant by chance alone.

Overall, visual acuity was a better indicator of detection performance; particularly the performance on the 6% visual acuity chart. The highest percentage of pilot groups showing a significant correlation between visual performance and detection distance occurred for visual acuity on the 6% contrast chart, 50% (4 of 8 groups). However, overall there was no statistically significant difference between the detection distance correlation coefficients for visual acuity on either of the three contrast charts and contrast sensitivity at any spatial frequency (Wilcoxon rank sum nonparametric analysis).

These results do not, in actuality, differ significantly from those reported previously by Ginsburg et al.[5] (see Appendix A); although we would disagree with their conclusions. In our opinion, neither our results nor theirs would appear to suggest that contrast sensitivity is a better predictor than visual acuity of aircraft detection performance of pilots. For instance, their results also show little repeatability for the contrast sensitivity at any particular spatial frequency to correlate with detection distance, even between days with similar visibility conditions. From their Figure, comparing foggy to foggy days, hazy to hazy days, or bright sun to other bright sun days does not reveal any spatial frequency contrast sensitivity repeatability. This lack of repeatability is in agreement with our results, and questions which spatial frequency, if any, is actually of importance for a particular visibility condition.

Additional statistical analysis (Wilcoxon rank sum) was also performed on the Ginsburg et al.[5] results (Appendix B). Comparison of their correlation coefficients gives probability levels of 0.27, 0.38, 0.41, 0.08, 0.13, and 0.09 for the difference between the 10 correlation coefficients reported for Snellen acuity and at each of 1, 2, 4, 8, 16, and 24 cpd spatial frequencies,

21

respectively. None of these comparisons is statistically significant, indicating no difference in the overall predictive ability of aircraft detection for contrast sensitivity versus visual acuity. This lack of statistical difference is also in agreement with our results; with the only difference between the two studies being the rank sum for contrast sensitivity being higher than for Snellen acuity in all but one case in their study, while the opposite was found in our study.

It is possible to find comparisons where two pilots had similar visual acuity but much different contrast sensitivity, with the lower sensitivity pilot having a shorter detection distance; as was done in the Ginsburg et al.[5] study. However, in our study it was just as frequent, if not more so, that two pilots having different contrast sensitivity but similar visual acuity, had very similar detection distances. For instance, on the 9/9 field trial, two pilots had contrast sensitivity at 12 cpd and 18 cpd that differed by a factor of 2.5 and had the same visual acuity, -0.28 and -0.26 logMar (20/10.6 and 20/10.9), but had almost exactly the same detection distance, 6.35 and 6.33 miles. In many other cases pilots had similar contrast sensitivity or similar visual acuity and yet had very different detection distances, suggesting that there are other factors than these visual parameters that play a role in target detection.

Any differences between the results for the two studies may be due mainly to differences in measuring and quantifying visual acuity and in measuring contrast sensitivity. We used visual acuity charts having smaller and more equal steps between letter sizes than found on the typical Snellen chart. In addition, the use of logMAR acuity allows highly individualized scores based upon the number of letters read correctly at each letter size; thus reducing lumping individuals into the same acuity group. We measured contrast sensitivity using the two-alternative forced choice (2-AFC) method, which reduces observer criterion effects and is considered a better method of measuring contrast sensitivity.[12] In the study by Ginsburg et al.[5], contrast sensitivity was measured using the method of increasing contrast, which is influenced by individual threshold criterion;[11] and it is possible that some pilots may have used similar individual criterion (e.g. conservative) during both aircraft detection and contrast threshold measurement that could have led to criterion influenced correlations. By using the 2-AFC method in our study, it is less likely that such correlations would have occurred, and could explain any difference between the two studies in the contrast sensitivity versus detection distance correlations.

Although a vision test may not correlate well with task performance in any particular study, the test may still be useful if it can identify individuals with worse task performance. This test

ability was evaluated by determining the number of pilots with the shortest or next shortest (i.e. worse) detection distance in their group of those pilots in the lower 10% of visual performance on the acuity charts and for each spatial frequency on the Optronix. As Table 5 shows, visual acuity was much better than contrast sensitivity at identifying the worse detection individuals. In particular, performance on the 6% contrast chart was the best indicator of the pilots with worse aircraft detection distance, while visual acuity on the normal high contrast chart was also relatively good at identifying these individuals. Pilots with lower contrast sensitivity at any spatial frequency were rarely the worse in their group at aircraft detection, suggesting that decreased contrast sensitivity in normals does not necessarily mean decreased performance. The usefulness of the Vistech chart in pilot screening is questionable since all of these pilots scored well within the normal levels issued by the company with the chart; and frequently a number of pilots had the same lowest score yet different detection distances.

Our results are in agreement with those of Kruk and Regan[9] and Monaco and Hamilton,[10] who also found no correlation between contrast sensitivity and the actual in-flight air-to-air aircraft detection performance of pilots. In addition, a recent study found no correlation between subjects' contrast sensitivity and their performance on a military vehicle target recognition task.[16] *Our findings indicate that additional testing of pilots for contrast sensitivity using vertical sine-wave gratings or the Vistech chart would not be useful in predicting performance on an aircraft detection task.*

One possible reason that lower contrast chart visual acuity correlated better than vertical contrast sensitivity with aircraft detection may be related to the target image at detection, although this was not monitored photographically. For these subjects, Figure 2 shows that the calculated corresponding spatial frequencies for acuities on the 6% contrast chart are higher than tested using sine wave gratings. The aircraft at detection appeared as a small dot or blob, which may be composed of numerous spatial frequencies and orientations. The visual system is appparently composed of mechanisms that are selective to both spatial frequency and orientation.[17] Letter acuity charts contain spatial frequency components at many orientations, and thus, visual acuity measurement may be a task more similar to aircraft detection than is contrast threshold for vertical sine wave gratings. The higher number of correlations using the 6% contrast chart suggests that both orientation and contrast contribute to this type of detection task. *The ability of the 6% contrast chart acuity to identify the worst individuals at this aircraft detection task would need to be confirmed with additional studies under varying conditions and for target recognition.*

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APPENDIX A

Ginsburg Summary of Results

FROM: GINSBURG et al, "CONTRAST SENSITIVITY PREDICTS TARGET DETECTION FIELD PERFORMANCE OF PILOTS"
PROCEEDINGS OF HUMAN FACTORS SOCIETY, 1983

DATE	FIELD TRIAL MILES	PILOT DETECTION RANGE (MILES) LONG-EST	PILOT DETECTION RANGE (MILES) SHORT-EST	PILOT DETECTION RANGE (MILES) AVE	PILOT DETECTION RANGE DIFFERENCES DIST-ANCE (MILES)	PILOT DETECTION RANGE DIFFERENCES TIME (SEC)	1 c/d	2 c/d	4 c/d	8 c/d	16 c/d	24 c/d	SA	COMMENTS
8/5	1-2	1.15	.73	1.00	.42	9.3	.49	.70 L,S	.27	.60 L,S	.66 L,S	.83 S	-.24 S	• 9 PILOTS • FOGGY
8/12	16+	9.61	7.69	8.61	1.92	49.3	-.10	.11	.01 S	.56 S	.57	.92 L,S	-.16 S	• 6 PILOTS • BRIGHT SUN • SOME HAZE
8/19	13	11.8	9.24	10.26	2.56	65.7	.28	.44	.87 L	.93 L,S	.38	.16	.47 L	• RAPIDLY CHANGING VISIBILITY • DUE TO FOG
8/26	5-7	5.99	4.60	5.41	1.39	35.9	-.21	.20 S	.38 S	.60	-.17	.17	-.86 L	• EXTREMELY FOGGY FOR ANALYSIS • 3 SIGHTS; SUBSEQUENT
9/9	.5-3	.48	.29	.38	.19	4.8	.13	.35	.17	.07	-.03	-.03	.18	• 9 PILOTS IN LATE AFTERNOON • TRIALS IN LATE AFTERNOON
9/22	15	14.50	7.97	9.9	6.52	168	.24	.38	.49	.06	.65 S	.57 L	.26 L	• WHITE AIRCRAFT • WHITE CLOUD BACKGROUND
9/29	15	7.51	5.50	6.77	2.01	51.7	.11	-.32	-.21	.31 L	.07	.00	.55 L	• RAPIDLY CHANGING VISIBILITY • DUE TO HAZE
10/6	5-7	5.50	4.38	5.04	1.12	28.9	-.01	.09	-.35	-.31	.23	.61 L	.31	• LATE AFTERNOON SUN
10/12	15	8.77	6.42	7.38	2.37	60.5	.01	.27	.39	.66	.59	.22	-.18	• LATE AFTERNOON SUN
10/27	15	9.97	6.69	8.5	3.28	84.5	-.28	.09	.07	.39	.28	.74	.77	

L THE HIGHEST CONTRAST SENSITIVITY OR SNELLEN ACUITY VALUE CORRESPONDED TO LONGEST DETECTION RANGE.

S THE LOWEST CONTRAST SENSITIVITY OR SNELLEN ACUITY VALUE CORRESPONDED TO SHORTEST DETECTION RANGE.

F CORRELATIONS WITH DETECTION RANGE WERE STATISTICALLY SIGNIFICANT AT THE .05 LEVEL OR BETTER.

Statistical Comparison of Ginsburg Correlation Coefficients

STATISTICAL COMPARISON BETWEEN
CORRELATION COEFFICIENTS
(FOR DATA OF GINSBURG ET AL.)   (WILCOXON RANK SUM)

PROBABILITY LEVEL:
METHOD OF INCREASING CONTRAST
- OPTRONIX (C/D)

	1	2	4	8	16	24
SNELLEN ACUITY	0.27 +	0.38	0.41	0.08	0.13	0.09

* NO SIGNIFICANT DIFFERENCES

+ VISUAL ACUITY SUM > CONTRAST SENSITIVITY SUM IN ONE CASE

CONTRAST SENSITIVITY SUM > VISUAL ACUITY SUM IN ALL OTHER CASES

- **NO STATISTICAL DIFFERENCE BETWEEN CONTRAST SENSITIVITY AND VISUAL ACUITY CORRELATION COEFFICIENTS WITH DETECTION DISTANCE.**

APPENDIX C

Field Group 1 Data

GROUP A (9/8/86)

SUBJ	AGE	RX	LOGMAR 3% VA	LOGMAR 6% VA	LOGMAR 85% VA	VSTECH 1.5	VSTECH 3	VSTECH 6	VSTECH 12	VSTECH 18
13	24	No	0.0375	-0.1375	-0.3500	7	8	8	8	7
26	27	No	0.1250	0.0125	-0.3000	6	7	7	7	6
27	24	Yes	0.2250	0.0125	-0.2000	7	8	8	8	8
30	24	Yes	0.2000	0.0000	-0.3625	7	7	8	8	8
31	26	No	0.0250	-0.0750	-0.3625	6	7	7	8	7
33	26	No	0.1000	-0.0750	-0.3250	7	8	7	8	7
37	29	No	0.1250	-0.1500	-0.3500	7	8	8	8	7
38	31	Yes	0.2125	0.0250	-0.2625	7	8	8	8	8
39	26	No	0.1250	-0.0625	-0.2500	7	8	7	8	7
40	25	No	0.1250	-0.0750	-0.2500	8	7	8	8	6
(n = 10)		MEAN	0.1300	-0.0525	-0.3013	6.90	7.60	7.60	7.90	7.10
		SD	0.0678	0.0629	0.0576	0.57	0.52	0.52	0.32	0.74

OPTRON 1.5	OPTRON 3	OPTRON 6	OPTRON 12	OPTRON 18	OPTRON 24	MEAN SECONDS	MEAN MILES	SD MILES	SORT MILES	
450.14	536.34	378.80	151.52	28.04	22.18	91.00	5.10	1.02	4.59	MIN
232.96	429.78	268.81	107.52	42.06	27.63	92.88	5.20	0.64	4.66	
261.39	191.97	268.81	151.88	66.65	31.01	91.60	5.13	0.74	5.01	
293.29	482.22	301.61	135.36	83.91	24.63	89.50	5.01	0.83	5.10	
164.93	135.90	190.30	85.41	74.79	12.35	82.00	4.59	0.76	5.13	
185.06	482.22	379.70	191.21	94.15	31.39	92.60	5.19	0.60	5.19	
261.39	271.17	338.41	120.64	66.65	27.63	93.90	5.25	0.57	5.19	
185.06	304.25	338.41	107.52	59.40	34.79	83.20	4.66	0.79	5.20	
164.93	482.22	311.66	106.41	52.95	22.18	95.00	5.32	0.57	5.25	
464.83	429.78	357.56	120.64	74.79	27.91	92.70	5.19	0.64	5.32	MAX
266.40	374.59	313.41	127.81	64.34	26.17	90.43	5.06	0.72	0.73	DIFF
109.98	138.63	58.83	30.55	19.63	6.30	4.40	0.25	0.14		

APPENDIX D

Field Group 2 Data

GROUP B (9-9-86)

SUBJ	AGE	RX	LOGMAR 3% VA	LOGMAR 6% VA	LOGMAR 85% VA	VSTECH 1.5	VSTECH 3	VSTECH 6	VSTECH 12	VSTECH 18
91	26	No	0.1500	-0.0625	-0.2750	7	8	8	8	8
92	26	No	0.2000	0.0375	-0.3000	8	8	8	6	6
93	23	No	0.1000	-0.1000	-0.3000	8	8	8	8	8
94	25	No	0.4125	0.1375	-0.1750	7	7	8	7	7
95	28	No	0.0000	-0.0500	-0.2625	7	8	8	7	7
97	23	Yes	0.1250	0.0375	-0.1375	7	7	8	8	5
98	31	Yes	0.1000	-0.0250	-0.3500	8	8	8	7	7
99	33	Yes	0.2500	0.0375	-0.1875	7	6	7	6	8
100	23	No	0.0375	-0.0875	-0.2750	8	8	8	8	7
(n = 9)		MEAN	0.1528	-0.0083	-0.2514	7.44	7.56	7.89	7.22	7.00
		SD	0.1236	0.0768	0.0694	0.53	0.73	0.33	0.83	1.00

OPTRON 1.5	OPTRON 3	OPTRON 6	OPTRON 12	OPTRON 18	OPTRON 24	MEAN SECONDS	MEAN MILES	SD MILES	SORT MILES
293.29	241.68	262.90	267.31	66.65	31.01	113.40	6.35	0.85	5.35 MIN
293.29	304.25	311.66	150.32	52.95	24.88	96.00	5.38	0.74	5.38
185.06	215.40	277.76	84.53	33.42	8.83	106.00	5.94	0.76	5.62
207.64	304.25	247.57	106.41	42.06	17.61	95.60	5.35	1.08	5.71
369.23	541.06	262.90	106.41	26.54	17.43	113.10	6.33	1.01	5.71
329.07	152.49	186.11	84.53	26.54	15.54	101.90	5.71	1.23	5.94
146.99	271.17	294.97	84.53	52.95	15.54	101.90	5.71	1.56	6.27
369.23	304.25	234.30	119.40	52.95	17.43	100.40	5.62	0.83	6.33
164.93	215.40	524.54	168.66	59.40	17.43	111.90	6.27	0.86	6.35 MAX
262.08	283.33	289.19	130.23	45.94	18.41	104.47	5.85	0.99	1.00 DIFF
87.30	109.53	95.40	59.36	14.50	6.25	7.80	0.39	0.27	

APPENDIX E

Field Group 3 Data

GROUP C (9-11-86)

SUBJ	AGE	RX	LOGMAR 3% VA	LOGMAR 6% VA	LOGMAR 85% VA	VSTECH 1.5	VSTECH 3	VSTECH 6	VSTECH 12	VSTECH 18
11	37	Yes	0.1375	-0.0750	-0.3000	8	8	7	8	8
45	28	No	0.1375	0.0125	-0.2750	8	7	8	8	6
52	30	No	0.2375	0.1000	-0.1000	7	8	8	7	6
55	29	No	0.1375	-0.0875	-0.2625	8	8	7	7	6
56	24	No	0.1125	-0.0625	-0.2625	7	8	8	8	8
57	24	Yes	0.1000	-0.0500	-0.3000	7	7	8	7	6
(n = 6)		MEAN	0.1438	-0.0271	-0.2500	7.50	7.67	7.67	7.50	6.67
		SD	0.0486	0.0713	0.0754	0.55	0.52	0.52	0.55	1.03

OPTRON 1.5	OPTRON 3	OPTRON 6	OPTRON 12	OPTRON 18	OPTRON 24	MEAN SECONDS	MEAN MILES	SD MILES	SORT MILES
414.28	429.78	311.66	189.24	83.91	22.18	119.60	6.70	0.36	5.50 MIN
369.23	429.78	147.84	67.14	33.42	21.95	116.60	6.53	0.61	5.70
146.99	383.04	277.76	75.35	26.54	15.54	98.20	5.50	0.51	6.40
293.29	304.25	220.64	106.41	37.48	17.43	129.70	7.26	1.68	6.53
146.99	429.78	621.84	106.41	52.95	31.32	114.20	6.40	1.26	6.70
261.39	271.17	277.76	75.35	66.65	12.47	101.80	5.70	0.29	7.26 MAX
272.03	374.64	309.58	103.32	50.16	20.15	113.35	6.35	0.79	1.76 DIFF
110.92	70.50	163.47	45.33	21.99	6.63	11.67	0.65	0.56	

Field Group 4 Data

GROUP D (9-12-86)

SUBJ	AGE	RX	LOGMAR 3% VA	LOGMAR 6% VA	LOGMAR 85% VA	VSTECH 1.5	VSTECH 3	VSTECH 6	VSTECH 12	VSTECH 18
9	22	Yes	0.1250	-0.0625	-0.3000	7	8	8	8	8
10	40	Yes	0.1500	-0.0625	-0.2500	8	8	8	8	8
28	32	No	0.1000	-0.0875	-0.2875	6	7	7	8	7
44	23	No	0.1625	0.0000	-0.2500	7	7	7	7	6
46	26	No	0.2500	0.0375	-0.1875	7	8	6	8	8
64	37	No	0.1250	-0.0500	-0.1875	7	8	8	8	7
88	29	No	0.1000	-0.0375	-0.3500	7	8	7	6	6
89	35	No	0.4125	0.1500	-0.1625	7	8	6	7	8
(n = 8)		MEAN	0.1781	-0.0141	-0.2469	7.00	7.75	7.13	7.50	7.25
		SD	0.1062	0.0772	0.0647	0.53	0.46	0.83	0.76	0.89

OPTRON 1.5	OPTRON 3	OPTRON 6	OPTRON 12	OPTRON 18	OPTRON 24	MEAN SECONDS	MEAN MILES	SD MILES	SORT MILES
261.39	341.39	196.65	133.97	42.06	19.76	102.40	5.73	1.53	3.99 MIN
261.39	383.04	156.19	133.97	66.65	27.91	78.10	4.37	0.49	4.35
207.64	304.25	311.66	119.40	37.48	13.98	77.70	4.35	1.09	4.37
131.00	429.78	330.96	106.41	21.08	15.54	91.30	5.11	0.42	4.79
261.39	341.39	196.65	67.14	26.54	15.54	87.60	4.91	0.59	4.91
293.29	482.22	196.65	67.14	21.08	13.98	85.60	4.79	0.65	4.93
104.07	191.97	220.64	67.14	37.48	22.18	88.10	4.93	0.48	5.11
94.99	173.99	128.00	42.36	16.75	13.98	71.20	3.99	0.79	5.73 MAX
201.89	331.00	217.17	92.19	33.64	17.86	85.25	4.77	0.76	1.74 DIFF
80.21	107.07	70.53	35.45	16.22	5.06	9.64	0.54	0.38	

APPENDIX G

Field Group 5 Data

GROUP E (9-15-86)

SUBJ	AGE	RX	LOGMAR 3% VA	LOGMAR 6% VA	LOGMAR 85% VA	VSTECH 1.5	VSTECH 3	VSTECH 6	VSTECH 12	VSTECH 18
50	28	No	0.1125	0.0000	-0.2875	8	8	8	8	7
59	24	No	0.2000	0.0500	-0.1750	6	7	8	6	6
61	23	No	0.0250	-0.0750	-0.2750	6	7	8	8	6
68	26	Yes	0.2250	0.0100	-0.2000	8	8	8	8	6
69	23	No	0.2250	0.0375	-0.1000	8	6	6	6	8
70	23	No	0.2125	0.0375	-0.2875	8	7	8	7	6
73	24	No	0.1080	0.0125	-0.1875	8	7	8	8	8
74	25	Yes	0.1000	-0.0375	-0.2750	7	8	8	6	8
(n = 8)		MEAN	0.1500	0.0044	-0.2234	7.38	7.25	7.75	7.13	6.88
		SD	0.0753	0.0422	0.0686	0.92	0.71	0.71	0.99	0.99

OPTRON 1.5	OPTRON 3	OPTRON 6	OPTRON 12	OPTRON 18	OPTRON 24	MEAN SECONDS	MEAN MILES	SD MILES	SORT MILES
521.55	383.04	277.76	75.35	37.48	14.77	108.20	6.06	1.29	5.42 MIN
414.28	383.04	349.70	133.97	29.77	13.98	96.80	5.42	0.92	6.06
464.83	304.25	220.64	84.53	26.54	15.54	122.50	6.86	0.84	6.06
261.39	429.78	349.70	106.41	47.18	15.70	118.30	6.62	1.08	6.17
185.06	171.09	124.08	33.65	16.75	9.90	117.50	6.58	0.63	6.58
232.96	304.25	311.66	133.97	52.95	15.70	110.20	6.17	1.15	6.62
293.29	341.39	277.76	133.97	47.18	14.77	108.30	6.06	1.28	6.86
369.23	341.39	311.66	119.40	74.79	22.18	122.70	6.87	1.12	6.87 MAX
342.82	332.28	277.87	102.66	41.58	15.32	113.06	6.33	1.04	1.45 DIFF
118.73	77.81	75.15	36.00	18.10	3.36	8.85	0.50	0.23	

APPENDIX H

Field Group 6 Data

GROUP F (9-16-86)

SUBJ	AGE	RX	LOGMAR 3% VA	LOGMAR 6% VA	LOGMAR 85% VA	VSTECH 1.5	VSTECH 3	VSTECH 6	VSTECH 12	VSTECH 18
23	27	No	0.1250	-0.0500	-0.2875	6	6	7	7	5
53	26	No	0.1125	-0.1000	-0.3000	8	7	7	7	7
71	22	No	0.2375	-0.0625	-0.2625	8	7	8	7	5
76	29	No	0.0625	-0.1375	-0.3000	7	8	8	7	6
77	29	No	0.0375	-0.1000	-0.3000	6	8	8	6	8
78	26	No	0.1125	-0.0750	-0.2875	6	8	8	8	6
80	23	No	0.0375	-0.1750	-0.3500	7	7	8	8	7
81	23	No	-0.0500	-0.1375	-0.3500	8	8	8	8	7
(n = 8)		MEAN	0.0844	-0.1047	-0.3047	7.00	7.38	7.75	7.25	6.38
		SD	0.0842	0.0428	0.0306	0.93	0.74	0.46	0.71	1.06

OPTRON 1.5	OPTRON 3	OPTRON 6	OPTRON 12	OPTRON 18	OPTRON 24	MEAN SECONDS	MEAN MILES	SD MILES	SORT MILES
207.64	429.78	277.76	150.32	42.06	22.18	97.20	5.44	0.87	4.48 MIN
232.96	304.25	349.70	168.66	52.95	17.43	100.00	5.60	0.64	5.12
369.23	271.17	247.57	84.53	42.06	17.61	80.00	4.48	0.69	5.30
232.96	241.68	155.08	150.37	59.40	19.76	94.60	5.30	0.64	5.37
261.39	304.25	196.65	67.14	42.06	13.98	95.90	5.37	0.70	5.44
185.06	304.25	247.57	119.40	37.48	19.76	106.70	5.98	1.18	5.47
329.07	241.68	247.57	119.40	42.06	22.18	91.40	5.12	0.75	5.60
261.39	304.25	349.70	84.53	66.65	22.18	97.70	5.47	1.09	5.98 MAX
259.96	300.17	258.95	118.05	48.09	19.39	95.44	5.34	0.82	1.50 DIFF
61.56	59.22	67.49	36.82	10.38	2.93	7.67	0.43	0.21	

APPENDIX I

Field Group 7 Data

GROUP 6 (9-17-86)

SUBJ	AGE	RX	LOGMAR 3% VA	LOGMAR 6% VA	LOGMAR 85% VA	VSTECH 1.5	VSTECH 3	VSTECH 6	VSTECH 12	VSTECH 18
49	24	No	0.1375	0.0000	-0.2750	8	8	8	8	7
54	25	No	0.3375	0.1250	-0.1875	6	8	7	7	6
60	24	No	0.1250	0.0000	-0.3000	8	8	8	8	8
67	24	Yes	0.1375	0.0250	-0.2000	8	7	8	8	6
74	25	Yes	0.1000	-0.0375	-0.2750	7	8	8	6	8
79	24	No	0.0625	-0.1375	-0.3625	7	8	8	8	8
83	24	No	0.0375	-0.0750	-0.2750	7	7	8	7	6
84	24	No	0.2375	-0.0625	-0.3000	6	8	8	7	8
85	24	No	0.2375	0.0750	-0.1500	7	8	8	8	8
(n = 9)		MEAN	0.1569	-0.0097	-0.2583	7.11	7.78	7.89	7.44	7.22
		SD	0.0960	0.0797	0.0664	0.78	0.44	0.33	0.73	0.97

OPTRON 1.5	OPTRON 3	OPTRON 6	OPTRON 12	OPTRON 18	OPTRON 24	MEAN SECONDS	MEAN MILES	SD MILES	SORT MILES
464.83	304.25	392.35	212.33	52.95	27.63	95.20	5.33	0.65	4.83 MIN
329.07	429.78	220.64	67.14	26.54	22.18	86.30	4.83	0.93	4.89
261.39	241.68	311.66	150.32	66.65	24.88	92.50	5.18	0.55	5.01
414.28	241.68	220.64	53.33	42.06	22.18	89.40	5.01	0.82	5.15
369.23	341.39	311.66	119.40	74.79	22.18	91.90	5.15	0.73	5.18
261.39	341.39	554.22	189.24	74.79	19.76	100.70	5.64	0.69	5.30
369.23	383.04	493.95	212.33	66.65	19.76	98.90	5.54	1.17	5.33
197.44	152.49	175.26	53.33	33.42	15.70	94.70	5.30	0.69	5.54
232.96	341.39	311.66	76.01	39.60	14.77	87.40	4.89	0.90	5.64 MAX
322.20	308.57	332.45	125.94	53.05	21.01	93.00	5.21	0.79	0.81 DIFF
89.59	84.26	127.41	67.14	18.39	4.08	4.91	0.28	0.19	

APPENDIX J

Field Group 8 Data

GROUP H (9-19-86)

SUBJ	AGE	RX	LOGMAR 3% VA	LOGMAR 6% VA	LOGMAR 85% VA	VSTECH 1.5	VSTECH 3	VSTECH 6	VSTECH 12	VSTECH 18
51	40	Yes	0.2000	0.0125	-0.3000	8	7	8	5	6
72	27	No	0.0125	-0.0500	-0.2625	8	8	8	8	8
87	32	No	0.1350	-0.0750	-0.2625	7	8	8	8	8
90	23	Yes	0.1250	-0.0750	-0.2875	7	7	8	7	8
102	38	No	0.0625	-0.0375	-0.1750	8	8	8	6	6
103	34	No	0.0500	-0.0875	-0.2625	7	8	7	7	8
104	33	No	0.0375	-0.1375	-0.2750	7	8	7	7	7
110	40	Yes	0.1500	-0.0625	-0.2500	8	8	8	8	8
111	37	Yes	0.1375	-0.0750	-0.3000	8	8	7	8	8
(n = 9)		MEAN	0.1011	-0.0653	-0.2639	7.56	7.78	7.67	7.11	7.44
		SD	0.0625	0.0404	0.0377	0.53	0.44	0.50	1.05	0.88

OPTRON 1.5	OPTRON 3	OPTRON 6	OPTRON 12	OPTRON 18	OPTRON 24	MEAN SECONDS	MEAN MILES	SD MILES	SORT MILES
207.64	241.68	349.70	53.33	26.54	13.86	119.30	6.68	1.01	6.43 MIN
261.39	241.68	311.66	150.32	66.65	24.88	126.00	7.06	0.45	6.60
131.00	482.22	554.22	189.24	47.18	22.18	120.00	6.72	0.26	6.64
261.39	215.40	196.65	67.14	23.65	13.98	126.30	7.07	0.18	6.66
369.23	429.78	311.66	133.97	47.18	13.98	118.50	6.64	0.15	6.68
261.39	341.39	349.70	59.84	21.08	15.70	117.80	6.60	0.49	6.68
207.61	304.29	311.71	150.32	37.48	19.76	119.30	6.68	0.18	6.72
261.39	383.04	156.19	133.97	66.65	27.91	114.80	6.43	0.31	7.06
414.28	429.78	311.66	189.24	83.91	22.18	119.00	6.66	0.04	7.07 MAX
263.92	341.03	317.01	125.26	46.70	19.38	120.11	6.73	0.34	0.64 DIFF
84.95	96.39	111.17	52.94	21.97	5.26	3.74	0.21	0.29	